DB-81-01

# A Literature Review of Research on the Actions of Drivers in Emergencies

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Published by:
The Policy Planning and Research Division
Ontario Ministry of Transportation and Communications
Hon. James W. Snow, Minister
H.F. Gilbert, Deputy Minister

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Research and Development Branch
Ministry of Transportation and Communications
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**October, 1981**

ACKNOWLEDGEMENTS

This report was reviewed and accepted by Frank Snelgrove, Project Manager, Research and Development Branch, Ontario Ministry of Transportation and Communications.

Linda Clifford, Research Officer of R & D Branch, MTC also took part in the reviews and made a number of suggestions to enhance the report.

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# I - INTRODUCTION

A critical conflict situation, as it applies to highway traffic accidents, has been defined by various authors as a conflict between two road users that will result in a collision unless one or both of the two parties responds correctly with a change in direction and/or acceleration.

Council, Sadof, Roper and Desper (1975) define an emergency maneuver as a co-ordinated effort by the driver, implemented in a compressed time interval, for the purpose of:

- avoiding an obstruction in the path of the vehicle, or
- keeping the vehicle in control when a malfunction occurs, or the normal forces of friction and traction are not sufficient to maintain the vehicle's normal course.

They state that this definition is broader than the definition of "collision avoidance" which is "the above-ordinary skills needed when two road users are in conflict and at least one of them is able to respond to eliminate the situation" (Human Factors Workshop, 1970). Additional considerations, for collision avoidance, according to Council et al include:

- the possibility that the collision can be prevented or ameliorated if one party makes the correct response;
- the situation and reaction occur in a compressed time interval that precludes recourse to normal driving skills; and
- the possible situations include those in which a vehicle may be forced into interaction with a fixed object off the road.

Hatterick and Bathurst (1976), in an NHTSA study, analysed 372 accidents involving 613 vehicles, which had been documented by the accident investigation team from Indiana University (1975). This study gave an overview of the accident picture:

- 31% of the accidents were single vehicle accidents,
- 69% were critical conflict accidents.

More important, Hatterick and Bathurst found that many of these critical conflict accidents have certain or probable potential for avoidance by driver action. Their accident analysis rated collisions on a 6-point scale of probability of causing or avoiding collisions. Of the conflict accidents, 47% were classified as having a certain or probable potential for avoidance via a driver-induced maneuver. A further 9% were rated as possible avoidance, totalling 56% of all critical conflict collisions which could be avoided. This represents at least 38% of the total accidents investigated.

It would appear, then, that multiple-vehicle, critical conflict collisions are major contributors to accidents, and a large proportion of these accidents are avoidable, or at least their severity can be reduced, by what the driver does. Given these findings, it would seem that the whole accident picture might be changed by a study of accident avoidance followed by some type of training.

The purpose of this literature review is to determine the state of the art that deals with what drivers do now in critical conflict situations, and to get some idea of what they might be trained to do.

Limitations of the Review

As the investigation of the literature proceeded, it became increasingly apparent that very few reports referred specifically to what drivers do in critical conflict situations, to the degree of precision required, and that none of the studies could be classified as real-world, hard core, controlled experimental research. The literature reviewed fell into 5 major categories: accident based analyses; demonstrations, field tests or pilot studies; simulator studies; emergency driver training courses; and other related studies. It is important to note the limitations of each of these types of study.

(a) Accident-based analyses can provide a logical framework within which to study emergency driving, but information available on accident reports generally refer only to physical characteristics, i.e., where the vehicle was at the time of the collision, and what maneuver the vehicle was performing. Only recently has any great interest been shown in the human factors of accidents, such as unsafe or faulty driver action, or the subjective concepts of drivers' perception, decision-making and information processing involved in critical conflict situations and responses. It is also important to note that accident analyses include only avoidance attempts that failed, that is, those that resulted in an accident. There were probably many more near miss situations where driver action did avoid an accident. Greater emphasis on near-accident analysis, through on-site observation and follow-up interview and questionnaire studies, might throw more light on the real world situation of what drivers do.

(b) There have been a number of activities which can be called demonstrations, field tests or pilot studies, but which are clearly not rigidly controlled experiments with appropriate sample size. They are not going to provide statistically acceptable proof of driver behaviour in critical conflict situations. They do provide a number of extremely promising areas for proper experimentation, an indication of the feasibility of continuing research, and a general idea of the kinds of results that might be found. However, it would appear that clear definitions and detailed measurement and observations are called for in future experiments.

(c) Simulators, theoretically, are useful research aids and allow for controlled experiments that can be replicated. They have logical appeal in being able to reproduce dangerous situations in a safe environment. But the very fact that it is simulating as opposed to creating situations removes the element of fear or panic for the driver. Simulator parameters are generally based on field test data. At present there is not sufficient known from field tests to accurately programme extensive computer responses. Generally speaking, what seems to happen with simulator studies is that the researcher becomes overwhelmed with the complexity of specifying not only the components of the situation to be simulated, but their interrelationship, the weighting and mathematical relationships between each of the components. Consequently, few simulator studies go further than equipment development and preliminary definition of the problems in the field.

(d) Much of the conventional wisdom and a feeling for what drivers do in emergency situations comes from conducting emergency driver training courses. However, most courses

tend to be institutionalized and carried out systematically, and thus may or may not form a good source for research questions. As well, the use of "safe" obstacles such as pylons, rubber tubes or styrofoam cars are not likely to represent a real-world, panic situation. The emphasis in these courses is clearly on the motor aspects of the task, and there are a set of training maneuvers which are used, with some modification, almost universally. However, the literature generally does not refer to the experimental or accident results from which these maneuvers, or the need for their teaching, are determined. Carrying out emergency driver training courses does give field experience of what ordinary drivers do before, during, and at the end of instruction. But results (with the exceptions reported in this review) are usually given only in terms of reduced accidents or injuries, or in terms of time, penalty points and number of pylons knocked down. Some mention is made of the effects of learning, incorrect versus correct strategy, and appropriate versus inappropriate responses, but little mention is made of what these strategies and responses were. There is only a supplementary attempt to cope with decision making in emergency training courses, but perhaps their greatest contribution, over and above the skills taught, is the exposure of drivers to a large number of "emergency situations". In spite of the "safe" obstacles used, this permits drivers to overcome their initial panic and begin to think about what to do in a driving situation. It gives increased confidence in the strategies selected, and develops an understanding of just how much vehicle control input is required to assure successful maneuvers in response to a specific situation.

(e) Contrasted with the paucity of studies on what drivers do is the abundance of other related studies on the physical factors, such as highway surfaces, tires, and vehicle components as they relate to skids and braking. A number of Transportation Research Records deal specifically with these topics. Also, a considerable amount of information is available from varied sources (e.g.: Hills, 1980) which relates to perception, information processing, decision making and psycho-motor skills. These will have some relevance to critical conflict avoidance, but have never been gathered together in an integrated manner to deal specifically with human abilities and limitations in emergencies.

One final word before we continue. As a topic of study, the whole area of driver actions in critical conflicts is unorganized and unstructured. In the process of splitting the available information into subject components, there is bound to be overlap, and the same study will appear in several different places. In order to keep a semblance of order, and to inject some sense of clarity, a synopsis is included at the end of each section. These are gathered together to form part of the summary and conclusions at the end of the report.

## II - SKILLS INVOLVED IN COLLISION AVOIDANCE

Collision avoidance is "the above-ordinary skill needed when two road users are in conflict, and at least one of them is able to respond to eliminate the situation" (Human Factors Workshop, 1970). These skills involve both avoiding an obstruction, and at the same time keeping the vehicle in control.

The avoidance response process in emergency or critical conflict situations is defined by Barrett and Alexander (1973) as the process of information detection, information processing, response selection and response execution in those circumstances for which the environmental consequences of the emitted response are imminent.

Bathurst (1980) also notes that the response process consists of:

- conflict perception, which involves detecting the elements of the current roadway situation and classifying it as threat or no threat, from the positions and relative motions of other vehicles;
- response selection, which involves the choice of vehicle control response from the repertory available to the driver; and
- response execution, which involves performance of the necessary motor activity and processing of feedback.

He adds that, in terms of skill development, an appropriate response is a combination of:

- correct perception - reaction and a "decision", and
- correct strategy plus response of sufficient magnitude.

Most evasive action (critical conflict emergency maneuvers) consists in changing speed (slow, stop, accelerate) or changing direction (left, right) or a combination of both. Another kind of evasive action is to make the other driver aware of the hazard so that he may also take evasive action (such as honking the horn or flashing headlights). But most of the available repertoire of avoidance skills is made up of variations of magnitude, timing and sequence of steering, braking and accelerating.

Hatterick and Bathurst (1976), using McKnights 1970 Driver Education Task Analysis, categorized response selection choices as:

- braking versus moving laterally,
- moving right versus moving left,
- accelerating versus braking,
- choice of braking technique,
- moving away from or towards a converging vehicle,
- choice among collisions.

They then identified basic (car control) and ancillary (vehicle-oriented and body position) responses for accident avoidance.

1. Car Control Responses
   - evasive steering
   - rapid braking
   - rapid acceleration
   - skid recovery
   - impact recovery
2. Vehicle Oriented Responses
   - observation
   - signals
3. Body Position Responses
   - front impact
   - rear impact
   - side impact

Maeda et al (1978) state that "emergency avoidance by turning of the steering wheel calls for consideration of both vehicle (stability) and driver characteristics,

inevitably involving complications, whereas in emergency avoidance by brake application only, vehicle characteristics alone need be considered".

According to Baker and Ross (1961), however, even a simple obstacle avoidance stop involves complicating attributes or road, driver and car. "Among other things, the driver must have the strength to apply the brakes, the car must have a braking system of suitable capacity for the driver's strength and car weight, and the road must have the proper surface and friction characteristics" (Baker and Ross, 1961).

According to Hatterick and Pain (1977), a straight ahead stop is rarely the preferred maneuver. By definition, any situation in which straight ahead braking will avoid a collision is not considered a critical conflict, since straight braking is a normal driving skill. Maneuver conditional success probabilities, in their study, rated drivers with time to attempt evasive action, and led to several findings of note:

- In conflicts, especially with converging or intersecting vehicles, these vehicles may be so close that braking guarantees a collision. This does not imply that braking is unimportant, but that braking will usually be performed in conjunction with some lateral movement.
- The second finding was the apparent value of acceleration as an avoidance maneuver. Among the 18 interesting subsituations, three are clearly best avoided by straight ahead acceleration, and two others by lateral movement and acceleration. If a driver is about to be rear-ended, then straight ahead acceleration, or acceleration ahead and generally right is advantageous.

It appears then that the compressed time interval inherent in a critical conflict necessitates the transformation of the

relatively simple skills of steering, braking and accelerating used in normal driving, into a highly co-ordinated reaction that requires additional skills of rapid accelerating and evasive steering. These new skills demand a different type of training, and a different learning experience for a young driver. This is sometimes considered non-defensive driving, because the individual is taught to steer out or accelerate out of certain situations, rather than slowing down to avoid them (Council et al, 1975).

Psychomotor skills of most drivers are adequate under routine conditions, but when faced with a critical conflict, drivers are likely to find themselves in a situation where the normal basic set of manipulations and decision-making skills are not sufficient to overcome the problem. Zavala et al (1972) note that these skills deteriorate under the stresses of speed, accuracy, task load and information load, stresses that can occur simultaneously under emergency driving conditions.

Council et al (1975) say basically the same thing: the emergency situation demands above-average perception, psychomotor, decision-making and manipulative ability to react quickly and accurately under the stress of the compressed time interval implicit in an emergency.

Not only that, but according to Zavala et al (1972), emergency evasive actions may conflict with previously learned responses and therefore require considerable practice. Mortimer and Olson (1973) explain that skills used in fundamental driving tasks are overlearned, and so driver variation will be small. But responses to potential crash-producing situations are not overlearned, and variability should be much greater, resulting in an increased probability that vehicle control will be inadequate for these conditions.

## SYNOPSIS

- The critical conflict situation demands above-average perception, response selection and response execution skills under the added stresses of speed, accuracy, task and information load.

- Straight braking is rarely the best avoidance maneuver; relatively simple skills of braking, steering and accelerating used in normal driving, must be transformed into a highly co-ordinated reaction requiring the additional skills of rapid acceleration, modulated braking and evasive steering.

- These skills are different from normal skills, and may even conflict with them. They require a different type of training, and must be overlearned to the point that normal driving skills are overlearned.

## III - DESCRIBING CRITICAL CONFLICT SITUATIONS

Accident analyses were reviewed in an attempt to describe critical conflict situations, and to determine why "special" and different skills are required.

Most authors emphasize that motor vehicle accidents are heterogeneous events with multiple causes. Baker and Ross (1961) state that cause is a combination of simultaneous and sequential circumstances without any one of which the accident could not have happened. Single vehicle accidents result from driver, road, vehicle and weather factors. But multi-vehicle conflict situations, with which we are most concerned, also include actions of other drivers. The combined speeds and maneuvers involved dictate that the situation occurs in a compressed time interval, making normal driving skills either inappropriate or impossible.

There are a number of ways in which accidents can be described, and depending on the way you approach the accident analysis, different literature is unearthed, and different conclusions are drawn.

(a) First of all, there is a multitude of literature which describes critical conflict accidents in terms of <u>where and when they occur, and what the vehicle was doing</u>. Forbes (1957) did a pilot study to investigate causes of near-accidents (179 reports from 122 drivers), and found a wide range of variables. The largest number of reports involved two vehicles, with three and one vehicle being next most frequent. Speeds ranged from stop to 65 mph, with a peak at 50 - 55 mph, and visibility was consistently good. Maneuvers included stopping, passing, turning etc., and incidents were

located equally in urban and rural territory. They occurred more frequently at intersections than on curves or hills, and those remaining occurred between intersections on streets or highways.

Hatterick and Bathurst (1976) made a super-8 movie of a 1½ hour ride through normal city, suburban, rural and freeway settings, and this was analyzed for potential conflicts and prevailing conditions. The results were integrated with the conceptual analysis of conflict situations, from McKnight's 1970 Driver Education Task Analysis. Nine basic conflict situations were found:

- intersecting vehicle (35% of all drivers in accidents)
- environmental (non-conflict) (15% " " " " " )
- oncoming vehicle (15% " " " " " )
- lead vehicle (11% " " " " " )
- following vehicle (10% " " " " " )
- converging vehicle ( 8% " " " " " )
- vehicle defect ( 3% " " " " " )
- other ( 2% " " " " " )
- backing ( 1% " " " " " )

From a literature review, Barrett and Alexander (1973) also made up a similar taxonomy of critical situations, and these made up 70% of accidents occurring in the highway system:

- passing
- following
- laterally moving vehicle
- laterally moving object
- tracking
- gap acceptance.

Hatterick and Pain (1977), from data of 372 accidents, found 5 basic situations:

- rapid closure with vehicle or obstacle ahead,
- rapid overtaking by following vehicle,
- approach of two vehicles on intersecting course,
- convergence of two adjacent vehicles,
- approach of two vehicles on head-on collision course.

Babarik (1968) found that struck-from-behind accidents accounted for 25% of all highway accidents and 30% of all injuries (from State of New York, Department of Motor Vehicle Accident Reports). In a study of accidents of taxicab drivers, he found that in one-way driving without intersections, the struck-from behind accident is the prevailing type.

(b) Other literature begins to look at accidents from a human factors point of view. Some of these have concentrated on unsafe or faulty driver actions leading to collision.

In 1976, Lohman et al did a study to identify a set of unsafe driving acts (committed with the full intent of the driver), by determining their frequency in accidents and traffic citations. These were ranked according to risk in the following order:

- turning in front of oncoming traffic,
- pulling in front of oncoming traffic,
- following too closely,
- running a traffic control,
- driving left of centre,
- speeding (least risky behaviour overall, but when only high speeds of 70 mph were considered, had a very high risk).

Forbes (1957) in his analysis of near accidents, also found driver faults. Most often cited were:

- Pushing through - oncoming car passing line of traffic against oncoming traffic, running red signal, crossing centre line to pass car stopped for left turn, passing and weaving in heavy traffic.
- Faulty driving habits - stopping suddenly in traffic without signal, signalling late, not checking rear before passing or turning, turning from wrong lane, wheel over centre line.
- Unexpected behaviour or condition of other driver - sudden slowing or stopping, running through red light, sudden turn, turning opposite from signal, sudden cutting in ahead, animal or child running into road.

(c) A final group of accident analyses concentrated on the <u>human factor and information processing errors involved in conflict accidents</u>.

Forbes (1957) in his analysis of near accidents, found that a common driver fault was misjudgement and errors of perception. This was related to speed or turn on curve, speed/rate of closing, passing opportunity, other driver's intended action, slippery road, seriousness of hazard (occurred with speeds of 15 - 30 mph as well as 50 - 60 mph).

Council et al (1975) also found that lack of training or judgment of closure speed caused a large number of rear-end collisions for young people, as well as collisions while pulling into the path of an oncoming vehicle. In longitudinal control, the driver must be able to detect whether the gap is opening or closing, as

well as the rate of change. Mortimer and Olson (1973) cite Michaels (1963) and Hoffman (1968), who found that the direction of change can be detected reliably if the distance between vehicles changes by 10 - 20%. Mortimer and Olson found no data on the rate of closure, but state that "experience suggests that drivers do poorly in this regard".

The Indiana University tri-level accident study (1975) involving on-scene accident investigation by a multi-disciplinary team found that human factor errors were involved in 92.6% of accidents.

| Major Categories: | | Minor Categories (Within Major): | |
|---|---|---|---|
| . recognition errors | 40-56% | . improper lookout | 23% |
| | | . speed | 17% |
| . decision errors | 28-52% | . inattention | 15% |
| . performance errors | 7-11% | . improper evasive action | 13% |
| . critical non-performance errors | 2% | . internal distraction | 9% |

Using this same data, Hatterick and Bathurst (1976) estimated that of all drivers in conflict situations, 46% did not perceive the danger in time to attempt evasive action.

Clayton (1972) did a questionnaire/interview survey of 348 road users and 210 accidents, followed by an at-scene study of road accidents by an interdisciplinary team of mechanical engineer, surgeon, traffic engineer and psychologist. Highway Code errors found were classified into perception, decision and implementation:

1. Perception (Unperceived Hazard)

   . Failure to look (did not receive total relevant sensory information available) - distraction at critical moment by signs, sideroads, landmarks, road restriction by parked car, junction with main road. The road user is viewed as incapable of monitoring two sources of traffic flow simultaneously. (15.3%)

   . Misperception (scanned relevant parts of the situation but did not perceive hazard correctly) - driver adopted incorrect set or perceptual expectation; unfavourable lighting, ambiguous signs etc. ( 9.9%)

   . Excessive speed for conditions - related to restrictions of available sight distance, bends, crests. (13.6%)

2. Decision (Perceived Hazard)

   . Panic reaction (overreacted to situation with excessive use of controls) - primarily caused by one road user suddenly infringing or threatening to infringe on the intended path of travel of another vehicle. The reacting road user, because of lack of driving experience, could not process all available perceptual information accurately and quickly, did not respond rationally to the situation, merely tried to stop as quickly as possible, and lost control. ( 4.8%)

   . Other known error of decision. (10.2%)

3. Implementation

. Error of implementation (road user used control other than the one he intended to use). (0%)

4. Non-Error (46.2%)

. Those accidents which did not include a driver error as defined by the Highway Code (Ministry of Transportation 1968)

Within the error groups failure to look and excessive speed accounted for over half the errors made.

## SYNOPSIS

- Accident analysis reports show that critical conflicts occur at intersections, and on straight roads and highways between intersections, in both rural and urban areas.

- Conflicts are often instigated by faulty driver action, such as following too close, running a traffic control, or turning in front of oncoming traffic.

- These accidents involve two or more vehicles, making moving maneuvers such as converging, intersecting, following, passing or approaching. This means that the critical conflict situation occurs in a very compressed time interval, making normal driving skills either inappropriate or impossible.

- Other accident studies have found that the majority of accidents involve human errors, and these errors occurred in each step of the response process: perception of the conflict, decision or selection of the response, and implementation of proper evasive action. One study showed that of all drivers in conflict situations, 46% did not perceive the danger in time to attempt evasive action.

## IV - WHAT DRIVERS DO IN CRITICAL CONFLICT SITUATIONS

Assessments of driver performance given in this review are hampered by a number of limitations. Some of these have been outlined in the introduction in a section entitled "Limitations of the Review".

As well as this, according to Mortimer and Olson (1973), an individual's performance in a given task varies from moment to moment, even when the environmental conditions are constant. Skills used in a fundamental driving task are overlearned, and so driver variation will be small. But responses to potential crash-producing situations are not overlearned, and variability should be much greater. This is also confounded by the difference that exists between drivers' abilities.

Keeping these limitations in mind, five major reports were reviewed, first to get a general overall picture of what drivers do, and to show how they attempt evasive action using combinations of all available maneuvers. This was followed by a more detailed look at reports which reviewed steering and braking as separate skills. No literature was found which dealt specifically with acceleration as an avoidance maneuver.

### (a) Overview

Bathurst's 1980 accident analysis of situation and response showed that appropriate avoidance responses are conspicuously absent. This could be due, he says, to failure to detect the conflict, lack of availability of correct response, or failure to select the correct response. Lack of response other than braking suggests that lack of response availability may be a major factor.

In the Indiana University multidisciplinary accident investigation (1975), police reports showed that many drivers were cited for improper evasive action. The two major subcategories were either fail to attempt appropriate evasive steering, or negation of what would have been a successful evasive steer through over-braking, with resultant front wheel lock-up, making steering input ineffective. Drivers frequently reported that they knew they had performed an inappropriate avoidance maneuver but, in the limited time available, had responded instinctively. The authors state that there is no support for the idea that driver knowledge, as measured by questionnaires, is related to accident involvement. There is a need to measure whether the drivers know the right answer, and how much time is needed to reach the correct decision.

In the NHTSA investigation of these same accident data, Hatterick and Bathurst (1976) found that 38% of accident drivers in conflict situations who have the time to attempt an evasive maneuver, steer straight only and brake with intent to stop before the object. They conducted a small simulator experiment to determine what skills could be taught via simulation. They found that simulator "subjects" were unable to perform evasive steering and modulative braking responses properly when these had to be carried out concurrently with perception, response-selection and motor responses.

Barrett, Kobayaski and Fox (1968) did a feasibility study for driver reaction to sudden pedestrian emergencies, using an automobile simulator. The experiment used 11 male subjects who drove at 25 mph. When they were 82.5 feet from a shed, a switch was tripped to release a dummy into the centre of the road.

All subjects tried to avoid the pedestrian either by braking or steering, or a combination of both. Only one subject was not summarized, because he was a pilot with a specific response set. His dominant response was to skirt the pedestrian completely instead of making a major attempt to brake. The results of the 10 remaining subjects divided drivers equally into a high injury group, who all hit the dummy, and a low injury group who either missed the dummy or hit at speeds less than 1 mph. The results were as follows:

- The low injury group initiated avoidance behaviour (brake or steer) much sooner (829 msec) than the crash group (1131 msec).
- All subjects braked. Three subjects in the low injury group used braking as the dominant response, and all of these reached full braking after initiation of the response. Only one of the five drivers in the crash group reached full braking. At least two of the crash group got to a maximum pressure for them and maintained it, even though it was not 100%.
- All subjects who depressed the brake rapidly, avoided the dummy. One subject, even though he had 100% depression, was slow to reach and could not avoid the dummy. Drivers in the crash group hit the dummy at between 10 and 20 mph, while the low injury group, because of braking, had lower speeds.
- Only one subject (the pilot) had steering as a dominant response. His maximum wheel turn was 54 degrees, while maximum wheel turn for all other subjects was 15.2 degrees.

- One subject had the fastest appropriate reaction, which was to steer left, but he didn't turn the wheel far enough to change the trajectory of the simulated vehicle. This subject also had the fastest brake reaction, but did not hit the brakes hard enough to decelerate the vehicle sufficiently to avoid a crash.
- It appears, as expected, that a combination of early response, rapid response sequence, and complete or extreme response yielded avoidance of the pedestrian. What was unexpected was that early response went with rapid response and extreme response within the same subject.

The authors suggest reasons why the subjects made no attempt to drive around the pedestrian. Braking, they say, may indeed be the dominant real-world response. If not, the situation may not have been real enough to make a real-world response. The subjects may have been unable to estimate distance accurately and may have thought they were braking enough. It may have been due to the unknown field and limited field of view in the simulator. The drivers may have considered that the pedestrian might have kept going ahead, and thus turning left would have been inappropriate. Or, drivers may have wanted to hit the pedestrian to see what would happen.

Bathurst (1980) describes a 3 module accident avoidance skill training course, consisting of:

1. Vehicle maneuver (circle, figure 8, serpentine, and brake while changing course) to familiarize the driver with the vehicle and high lateral acceleration G forces.

2. Surprise fixed obstacle avoidance. A bridge structure was built to span the roadway. A number of plastic tubes were attached. These were normally held horizontally but selected teeth could be released to drop to create barriers and holes in the path. Both the size and position of the opening remained unknown to the driver until just before execution of the vehicle maneuver. Runs were conducted at 25 mph and preview distance was 1 to 1½ seconds.
3. Intersecting vehicle avoidance. Large screens were placed by the side of the roadway and a small styrofoam vehicle was propelled from behind the screens to intersect with the subject's vehicle. Drivers approached at 25 mph and were instructed to apply the brakes and try to steer behind the styrofoam car if they thought they would hit it in the front, and to accelerate and steer away from the car if they thought they would hit it in the rear.

Sixteen students, ranging from newly licensed teenagers to experienced adults, took part in the realistic crash avoidance trials. Because of the small sample size, this study is qualified as a field test. It cannot provide conclusive evidence, but does give an idea of what drivers do. Based on the written report, and on a discussion with Mr. Bathurst, the important outcomes of the research are as follows:

. On the average, drivers usually made the correct decision about 80% of the time, but the magnitude of the response, especially for novices, was generally too small and too slow. There was no change in the ability to make the correct decision over the course of the experiment, nor were there any differences between young and experienced drivers.

- Untrained drivers react differently, with regard to the use of speed or steering as the predominant initial response. As drivers become more experienced, the response is initiated earlier. This is important, and may in fact be the goal to be attained, since early response requires less input into the system, and creates less instability in the vehicle or less lateral acceleration which has later to be corrected.
- The driver who was best at fixed obstacle avoidance was worst at intersecting vehicle avoidance, and another subject showed opposite results.
- 82% of the collisions that occurred in the first half of training followed the implementation of a fundamentally appropriate response. During the second half of training, only inappropriate responses produced crashes.
- A dramatic change of attitude took place, especially in young males. Initially they tended to think they knew all they needed to know. After training they were more willing to accept that they were vulnerable to crash, and had increased confidence to make a decision and follow it through.
- The retest was the most promising and unexpected finding of the whole study. Nine months after training, every driver had improved in ability. More important, the novices, who had not reached the level of expertise of other drivers at the end of training, had gained parity 9 months later. When questioned, students revealed that a considerable amount of mental practice had taken place, and they carried out avoidance preplanning while they were on the road.

Koppa and Hayes (1976) found different results. They used an instrumented vehicle during replication and surprise test maneuvers (on simulated roadways and on a

test pad) to determine the extent to which drivers utilize the full capabilities of the vehicle. Surprise tests presented the driver with unexpected obstacles or traffic control devices, and drivers were free to maneuver as they saw fit. They noted that at a deceleration command, drivers could generally achieve or exceed that required for at least partial brake lock-up, but this seldom occurred in the surprise maneuvers. However, they did find that loss of control (yaw, or heading, unstable condition) always occurred during the recovery phase of an avoidance or lane change maneuver. Driver input and response parameters usually increased as task difficulty increased (where allowed maneuver time or distance decreased) up to a point, and then fell off. This indicates, say the authors, that drivers tend to give up if the task seems impossible.

Finally, Rundkvist (1973) wrote a report on a field test to determine how the average driver behaves during unexpected emergency situations, and whether or not having steerability works to his advantage. He used a plastic foam dummy car to test collisions at road junctions, running into a vehicle from behind at 70 kph. Instruments registered steering wheel movement, brake pedal depression time, wheel speed when anti-lock system was functioning, reaction time and distance, and final stop position. This looks like a promising study, but at the time of publication, tests were still going on, and there is as yet no evaluation. However, there are all kinds of noted reactions, from full brake going straight ahead, to almost no braking but steering left or right. It is also interesting to note that drivers' first reactions to identifying the dummy ranged from child, concrete block, reindeer (this was a Swedish study), to small car and railway wagon.

Rundkvist's study looks tantalizing, but the remaining literature seems to show that the critical conflict behaviour of drivers, in very general terms, is as follows:

## SYNOPSIS

- Drivers find it difficult to perform evasive steering and modulative braking responses properly when these have to be carried out concurrently with perception, response selection and motor responses.

- Improper evasive actions are mainly failure to attempt appropriate evasive steer, or negation of what would have been a successful evasive steer through over-braking, with resultant front wheel lock-up, making steering input ineffective.

- 38% of accident drivers in conflict situations, who had the time to attempt an evasive maneuver, steered straight only and braked with the intent to stop before the object. Many of these are likely doing this out of panic or instinct, rather than it being a consciously selected response.

- Whatever their evasive action, the magnitude of the response is generally too small or too slow to be effective.

- There is also a problem of loss of control during the recovery phase of an evasive maneuver, especially for novices.

(b) Braking

Aspects of longitudinal vehicle control are discussed by Mortimer and Olson (1973). They quote Carpenter (1955) who indicated that about 96% of brake applications involved decelerations of 0.3G or less, and that about 0.1% are 0.5G or above. They quote Mortimer and Segal (1970) and Kummer and Meyer (1967) to show that brake applications occur approximately once every mile. The average driver, therefore, is involved in about 10 severe (that is, 0.5G or above) brake maneuvers per year. This translates into about 2 million such severe brake maneuvers involving passenger vehicles each day in the United States. Mortimer and Olson do not say whether or not these are emergency or critical conflict maneuvers.

The method of maximum speed reduction presently taught is that of modulated brake application, one in which the brake is fully depressed to the point of locking the wheels, released slightly to allow the wheels to rotate, and the process repeated until the vehicle comes to a stop.

However, Mortimer and Olson conducted braking tests and found that drivers are relatively inefficient in modulating brakes in severe braking maneuvers so as to obtain maximum deceleration potentially available to them, particularly on slippery surfaces. The difference between driver performance is large on dry pavement and quite small in low friction conditions, but all performance results are rather poor.

Hatterick and Pain (1977) from the analysis of 372 case histories of accidents, noted that 45% of drivers in conflict situations lock-up their wheels sometime during the avoidance attempt. This compares with 15% locked wheel accidents derived from police accident report data (Rundkvist, 1973).

Past studies have looked at the relative braking distances of a number of braking techniques, including pump and lock, pump and no lock, modulated or "threshold" braking, and 4-wheel lock braking. These studies have shown that there is a difference in braking distances with different braking techniques, and that, except for high speed situations and low friction surfaces, the 4-wheel lock technique generally produces shorter braking distances. (Zipkes, 1944; Norman, 1953; and Starks, 1953; all in "Research on Road Safety", 1963; and Hieatt, 1980)

The effect on the direction of the vehicle varies dramatically according to whether it is the front or the rear wheels which lock. Front wheel lock-up will generally mean that the vehicle goes straight ahead, but the driver must release the brake to steer. Rear wheel lock-up generally means that the rear of the vehicle will slew or twist, and releasing the brake may complicate the issue. A properly executed 4-wheel lock-up will generally result in the vehicle going straight ahead. Deviations from a straight-ahead stop can occur as a result of uneven surface friction, camber of the road, or nonsimultaneous locking of the wheels.

While the front wheels are locked, either from a front wheel lock or a 4-wheel lock, the driver's steering input has no effect. For the driver to regain steering control, it is necessary to release the brake and permit the front wheels to roll.

Mortimer and Olson (1973) cite a study by Murphy and DiLorenzo (1972), that varied deceleration/pedal force gain and compared results with an anti-lock brake system. Murphy et al were able to determine that:

- On dry asphalt, an advanced anti-lock brake system was no more than 68% efficient, or about the same as the best driver's performance.
- On wet painted surface, the anti-lock device was able to extract 95% of available deceleration, compared to less than 50% gained by drivers.

In these cases the method of braking is not known, however the results do show that on wet low friction surfaces the antilock system provided better braking.

Anti-lock devices, and/or the teaching of efficient braking techniques, is also important in light of the fact that locked front wheels make steering input impossible. Pulling (1976) quotes a Swedish accident study which found that 40 - 50% of collisions could have been avoided or reduced by steering capability (Bohlin et al, 1973). They do not mention whether steering capability was in addition to, or instead of braking.

While not based on research, observations of advanced driver training courses that teach 4-wheel lock and threshold braking (Mossport Safety Group, 1977 manual based on courses in Europe and the U.S.), showed that the first time drivers attempted to 4-wheel lock, they often had trouble locking all 4 wheels. In some instances they succeeded in locking only the rear 2 wheels, resulting in a twisting of the vehicle. Of equal importance, however, was that when drivers tried emergency stops using their own preferred technique, their success in stopping under control was no better than with the 4-wheel lock.

Hieatt (1979) conducted a small sample demonstration in which six untrained subjects were required to do an emergency stop from 90 kph using any technique they wished. The pretraining results showed that even in this small sample, drivers used a variety of different emergency stopping techniques. Half of the drivers lost control of the vehicle while stopping.

Rundkvist's accident investigation (1973) using police reports, interviews and literature review, showed that 10 - 15% of all reported accidents involved locked wheels. The typical locked wheel collision happens to a vehicle driven by a new driver who approaches a road junction at 50 kph on a slippery surface and meets another vehicle from right or left. Typical situations for damage accidents included running into a vehicle from behind (25.7%), collision with a vehicle in a road junction (18.4%), and running off the road due to speeding (12.8%). He estimated that 70% of accidents could have been avoided if vehicles had been steerable, and that drivers attempted to steer in 40 - 50% of cases when the possibility of preventing the accident was good. Therefore, Rundkvist concludes, 4 - 7.5% of all accidents could have been avoided or reduced if vehicles were steerable during emergency braking.

Pulling (1976) quotes a German HUK Verband investigation of skidding accidents (1972 which found that four-wheel anti-lock braking systems would have minimized or avoided the accident in 7.1% of cases, and with good use in another 8.3%. The Indiana University accident

investigation (1975) estimated that a two-wheel anti-lock brake system would have prevented or reduced the severity of 1.9% of accidents, and that four-wheel anti-lock braking had a 9.3% potential payoff.

Council et al (1975) cite Barry, Pitts and Roper (1974), who found that skidding was involved in 61% of all accidents, and were responsible for the major proportion of multiple vehicle emergency situations. Skidding was a factor in 10.6% of all single vehicle crashes and 4.2% of all multi-vehicle crashes. They use this information to suggest training of:

- skid situation,
- evasive maneuvers and controlled braking exercise, combined with serpentine, to teach judgment of gap clearance and closure rate,
- controlled braking, to teach how to avoid an obstacle in the path of the vehicle while bringing the vehicle to a stop in the shortest possible distance without skidding or locking brakes.

## SYNOPSIS


- Drivers are inefficient in modulating brakes to obtain the maximum deceleration available. According to one accident analysis, about 45% of drivers in conflict situations locked-up their wheels during the avoidance attempt. This compares to 15% derived from police report data.

- Four-wheel lock generally produces shorter braking distances, except for high speed, low friction situations, but drivers generally can achieve only front or rear wheel lock. Rear wheel lock produces skidding or slewing.

- Four wheel and front wheel lock also makes steering impossible. It is estimated that 10 - 15% of accidents involve locked wheels, and that 70% of these (4 - 7.5% of all accidents) could have been avoided if vehicles had been steerable.

- Anti-lock devices have been proposed to both maximize the available deceleration on slippery surfaces, and to maintain steering capability.

(c) Steering

Steering control has been investigated by the study of obstacle avoidance without the use of the brake pedal.

According to Mortimer and Olson (1973), drivers increase their steering control response frequency bandwidth, and expend more effort, as task difficulty increases. In a steering task, they found that 74% of drivers were able to control successfully at 0.5G lateral acceleration at 50 mph, and 50% at 60 mph. Variability between drivers was greatest in lane-change tasks, suggesting that this type of collision avoidance maneuver offered a potential improvement by training.

A report by Reid et al (1980) for MTC, described a fixed base driver simulator study of driver vehicle control during an obstacle avoidance maneuver, without the use of brakes. The avoidance maneuver was triggered by the fall of one pole of many lining the road in front of the driver. The testing measured vehicle's clearance margin while passing the barricade, and time taken to reach steering wheel angle of 20 degrees, following the release of the barricade. Preview distances (distance from driver to barrier when barrier was first detected) were either short (23 meters) or long (46 meters).

It was found that driver steering response follows the same general pattern for both preview distances, and can be characterised as a rapid pulse-type steering wheel movement to avoid the obstacle, followed by a similar opposing pulse which limits the excursion into the passing lane and starts the return of the vehicle back to the original lane. Peak values for steering wheel response are always greatest for short preview, but the width of the first pulse is the same for both distances. The second pulse is usually slightly wider than the first for short preview, and much wider for long preview. The steering wheel activity following the double pulse is considerably less violent, and appears

to be designed to produce a smooth transition back to the original driving lane.

At forward speeds of 50 kph, the short preview represented quite a demanding task. The majority of unsuccessful maneuvers were caused by striking the barricade rather than by deviating onto the shoulder, but there were fewer failures after training. In most cases, the combined barrier detection time and steering response time was about the same for a given subject, with shorter preview slightly smaller than for longer preview. In general, the vehicle is to the right of centre in the passing lane when the barricade is reached, but because of the greater time allowance, clearance margin and time taken to reach 20 degree steering angle were both smaller for short preview than for long preview. In some cases where steering angle response lagged behind the usual response (from inattention or intentional change in driving technique), this did not alter the clearance margin.

Maeda et al (1978) in Japan note that some auto accidents are caused by turning the steering wheel so abruptly that the vehicle goes out of control. Their study used a simulator on a test track, where subjects were instructed to avoid a sudden obstacle without the application of brakes. In the emergency avoidance test, the obstacle jumped into the road 1.3 seconds before the collision would occur, but the subject expected the obstacle. In the surprise test, a sudden lane change was unexpected, and time allowance was 1.8 seconds.

In the emergency avoidance test (informed drivers), reaction time was 0.4 to 0.5 seconds; maximum steering angle in the first steering input was 200 - 230 degrees (corresponding with maximum possible steering angle with

hands kept in the same place); and maximum steering angular velocity was 700 - 900 degrees per second (this is quick). There was no significant difference in these results between experienced and inexperienced drivers, but reaction time showed great difference among individual drivers.

During the surprise (sudden lane change) test, none of the drivers successfully avoided collision with the obstacle, because it was more than one second after the surprise appearance of the obstacle that any driver started to turn the wheel. Compared with informed drivers, these uninformed drivers took more time to start steering after the appearance of the obstacle, had decreased response gain, and were slower to start turning the wheel at a sharp steering angle. The same driver, whether informed or not, showed the same steering pattern.

The authors found that experienced drivers foresee upcoming conditions better than inexperienced drivers. While both have the same initial steering input to avoid the unexpected obstacle, experienced drivers displayed more stable performance in subsequent control of the vehicle. Inexperienced drivers made repeated correction of control steering so that the path of the vehicle was unstable. When vehicle yaw response is greatly delayed, inexperienced drivers may lose control, while experienced drivers will secure control of the vehicle. The response of experienced and inexperienced drivers is nearly the same when yaw response lag is small.

Finally, as part of our relentless search for any information on what drivers actually do in emergencies, we will include a personal experience described by Overend (1972), who took part in a Winter and Emergency Driving Workshop run by the National Safety Council. The purpose of the exercise was to train students in handling the capability of the car, and decrease their tendency toward panic braking, since locked wheels have no cornering

capability. Students were instructed to drive down a path at speed, and when the car was even with the last set of cones, the instructor would tell them whether to go right or left of the barrier. The subjects were to avoid the barrier without using their brakes.

"At 25 mph the maneuver was not difficult, but my steering was jerky. At 30 - 35 mph there was less time to respond to the command and I found myself going right when he said left, because I had subconsciously made up my mind which way to go. At 40 mph I knocked down cones and stepped on the brakes, despite the prohibition. The limit for this maneuver was 35 mph." And about skidding, "In a skid I felt the rear of the car lurch to the left as the rear wheels locked (25 mph, no braking allowed). I swung the wheel to the left as fast as I could, but not soon enough - the car spun around and slid into the snow bank on the right. What I had done wrong was not holding the wheel in the 9 and 3 position, and therefore did not have full 180 degree range of motion. The wheel turned too jerkily and too late. Worst of all, I panicked and stepped on the brake when the car started to slide. I was not aware I had done all these things. I spun out twice more, when the car was sent into an experimental skid, due to oversteering and turning too far into the skid."

## SYNOPSIS


- Studies on steering, as a skill separate from braking, note that drivers in critical conflict situations expend more effort and increase their steering control responses as task difficulty increases.

- Despite these efforts, avoidance attempts are not always successful, where available response time is very low.

- In the process of the avoidance response, drivers may turn the wheel so abruptly that they lose control of the vehicle.

- Both experienced and novice drivers have the same initial input to avoid an obstacle, but experienced drivers display more stable performance in subsequent control of the vehicle.

## V - OTHER RELATED STUDIES (PERCEPTUAL AND RESPONSE SELECTION SKILLS)

Barrett and Alexander (1973) reviewed relevant literature and found very few studies even peripherally concerned with driver decision-making behaviour, and no systematic research which measured a range of individual (causal) predictors. However, they identified four intrinsic predictors for which they felt sufficient theoretical and empirical evidence existed to demonstrate relevance to effective decision-making in preventing and identifying critical situations. These were:

- Perceptual style - ability of an individual to extract relevant cues from the driving scene,
- Reaction pattern - the relation between perceived speed and motor speed,
- Frustration tolerance - the ability to control hostility in frustrating driving conditions, and
- Attention - performance under conditions of task overload and monotony.

Hatterick and Bathurst (1976) developed flow charts of minimum behavioural and information processing sequences necessary for avoiding any one of a number of situations. An example is shown in Fig. 1, Driver Behaviour in Intersecting Vehicle Conflict. The authors point out that these flow charts accentuate the role of information processing, and conclude from their analyses that present programmes in accident avoidance training are placing the emphasis in the wrong place: at present, most emergency driving courses concentrate on motor skills, and there is little or no emphasis on perceptual and response selection skills.

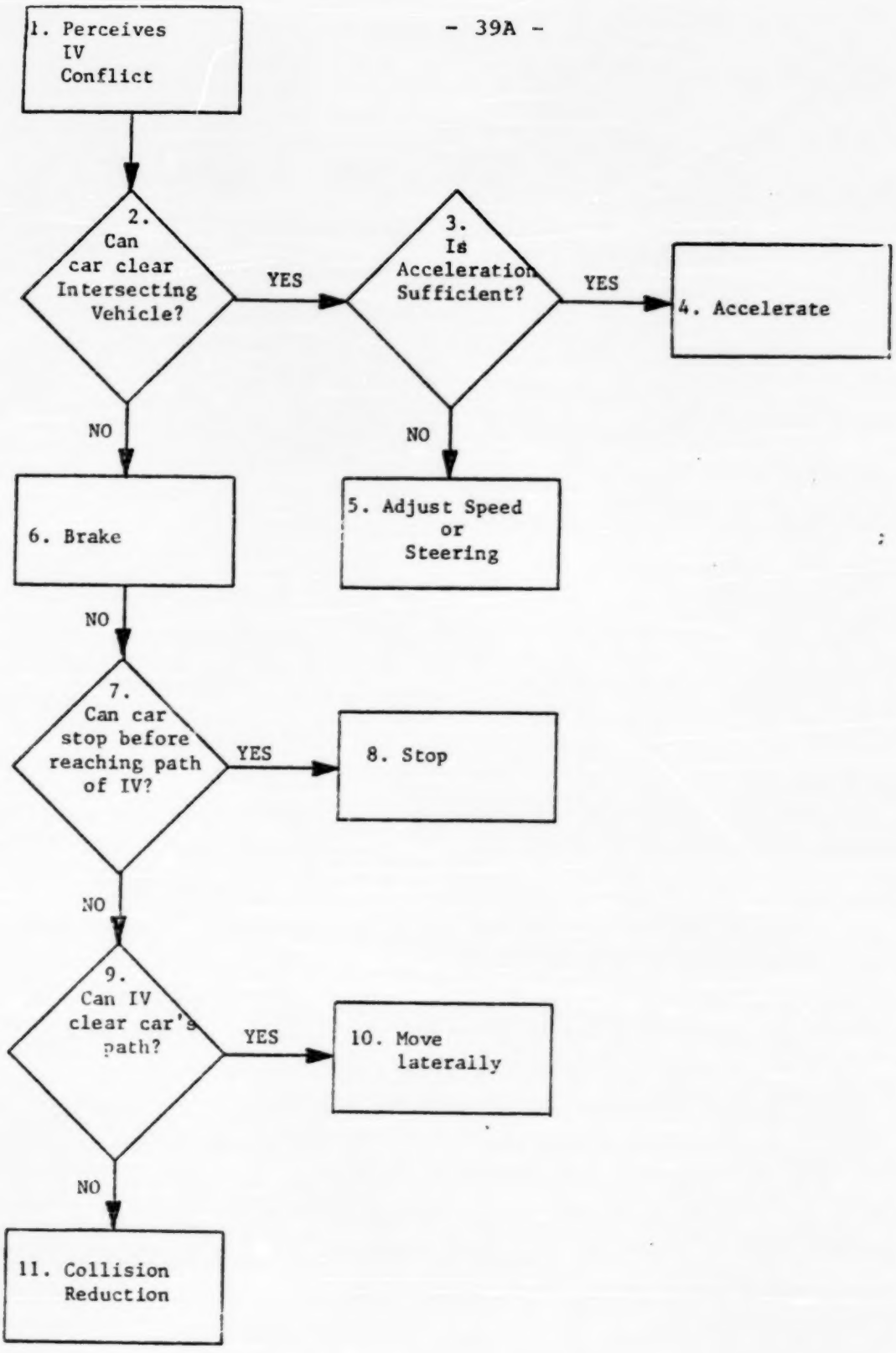


FIGURE 1 DRIVER BEHAVIOUR IN INTERSECTING VEHICLE CONFLICT

(a) Perceptual style has received some attention in the research, mostly in studies of field dependent/field independent drivers. Field independence, according to Goodenough (1976) is the capacity to overcome embedding contexts in perceptual functioning. In field dependence, perception is dominated by the immediately given organization of the stimulus field. Field dependent drivers are slow to detect the development of an emergency in which the relevant cues are camouflaged in the sign field. One might expect that violations and accidents which involve failure to heed road signs may be more frequent among field dependent drivers.

Barrett and Thornton (1968) conducted an automobile simulator study using a dummy pedestrian. During emergency trials, responses were measured in terms of initial brake reaction time, deceleration rate, and hit-miss dichotomy, and were compared to the results of a perception (rod and frame) test. Results supported the hypothesis that field dependent drivers are less effective in responding to emergency situations. They tended to have longer brake reaction times, lower deceleration rates, and hit the dummy more often than field independent drivers.

In 1974, Olson (cited in Goodenough, 1976) did a 3-car platoon driving experiment over a test field. The first car underwent a series of programmed acceleration and deceleration. The third car was driven by the subject, and his reactions to these changes were observed. Two conditions were run: normal, where the first car in line was visible to the subject; and closed, where the subject's view of the lead car was screened. Results showed that under the normal condition, field independent drivers make more use of lead car cues and had shorter

reaction times than field dependent drivers. They showed dramatic reduction in reaction times when the lead car was visible, while field dependent drivers showed little difference in behaviour.

(b) Driver decision-making is difficult to measure, and can only be inferred from behavioural assessments or driver interviews.

Perhaps one of the most interesting theoretical studies on evasive action decision-making was done by Prentice (1974), who hypothesizes that game theory methodology may be used by drivers in choosing an accident avoidance strategy. He describes a typical two-car intersection accident situation:

> Miss P, driving west at 22 mph, failed to see a stop sign, entered the intersection, noticed a car approaching from the left, locked her brakes and skidded 23 feet before being struck near the centre of the intersection on her left side.
>
> Mr. M, driving north at 23 mph, was four car lengths from the intersection, noticed Miss P entering from his right, locked his brakes, but was unable to avoid the crash as he skidded 12 feet to hit her car on the right side.

In this case, locked brakes "increased the stopping distances and prevented steering control". But many studies have shown that it is difficult for drivers to modulate their pedal load to achieve maximum brake short of lock, especially in a panic situation, and

therefore all emergency braking is assumed to be lock. If this is so, what other options were available, and what should these drivers have done?

Miss P could brake and attempt to avoid entering the path of the opposing vehicle, or she could accelerate straight ahead and hope to clear the intersection. A turn would be unwise, because she was not psychologically prepared for a quick turn, had little reaction time, and a turn might place her car in the path of an opposing vehicle. Whatever action she takes to avoid the crash, her success will depend on what evasive action Mr. M takes. Mr. M could steer right and try to go around the rear of Miss P's car, but this will avoid a crash only if Miss P accelerates. He could steer left and accelerate to go around the front of her car, but this will avoid a crash only if she brakes. Finally, he could brake straight and try to reduce the severity of the crash.

This situation may be thought of as a two-person constant sum game, where the participants are compatriots who receive the same payoff, as opposed to competitors, where one wins and one loses. The matrix shown below represents the possible combinations of strategies, indicating the consequences of pairs of strategies. For each pair of strategies, certain factors will influence the consequence or payoff, most noteworth of which is that for both vehicles, speed is directly proportional to severity of the crash. The matrix shows the order of severity for all options, 0 indicates an accident avoidance, 10 the most serious collision and 5 and 6 intermediate levels of severity.

| | MISS P | | |
|---|---|---|---|
| MR. M | Accelerate | Brake | Maximum |
| Accelerate, Steer Left | 10 | 0 | 10 |
| Steer Right | 0 | 6 | 6 |
| Brake | 5 | 5 | 5 |
| Maximum | 10 | 6 | |

The object of the game theory is to determine the optimal strategy for each driver. Both drivers wish to minimize loss by avoiding a crash, but unfortunately, since neither driver knows what action the other is planning to take, each is uncertain what act he or she should take. Therefore, a good decision might be for each driver to pick a strategy that minimizes the loss regardless of what the other driver does. Thus, although Miss P and Mr. M both have evasive actions available to them that could conceivably avoid a crash, they choose to forego these and choose an action that will assure a low level of crash severity. In this case the lowest level of crash severity guaranteed is a 5 resulting from both Miss. P and Mr. M. braking.

The game theory approach is academically interesting. However, according to Baker and Ross (1961), decisions are by no means the rational conclusions of a reflective process. This is simply for want of time, and is also influenced by prejudices, overconfidence, fear or agression, and often reflects the degree of risk a driver is willing to take.

Bathurst, in his 1980 report on accident avoidance skill training discussed student attitude and perception of their ability. His initial concern, following student exposure to tasks which required

high G force loading and quick and aggressive maneuvering, was "the perception of being a superior driver because of demonstrated vehicle handling expertise might be counter-productive to the accident picture.

However, after some reality testing and student failure with tasks which required rapid avoidance maneuvering, these attitudes of superiority were radically modified.

## SYNOPSIS

- Perceptual skills have received some attention in the research, in relation to field dependence/ independence (the ability of the driver to extract relevant information from the environment). Field dependent drivers are slow to detect the development of an emergency, and are less effective in responding, than field independent drivers.

- Driver decision-making or response selection has been discussed by one author with a "game theory approach". A mathematical model of perceived risk/ severity attempts to explain why drivers might choose an "incorrect" strategy (such as straight braking) that may not ensure crash avoidance, but will minimize loss regardless of what the other driver does.

- Other authors maintain that decisions are not the rational conclusions of a reflective process, but are influenced by time, prejudice, overconfidence, fear or aggression.

- There is some feeling in the literature that present advanced driver training emphasises motor skills, with not enough attention paid to perceptual or response selection skills.

## SUMMARY

The literature gives evidence that multiple vehicle, critical conflict situations are major contributors to accidents (according to one study, they comprise 69% of all collisions). More important, another study showed that a large proportion (56%) of these accidents are avoidable, or at least their severity can be reduced, by what the driver does. Given these findings, it would seem that the whole accident picture might be changed by a study of accident avoidance followed by some type of training. For this reason, a literature review of the research on actions of drivers in critical conflict situations was conducted.

No real-world, properly controlled research on the actions of drivers in emergencies, looking in great detail at what these drivers do, could be found for this review. The available literature included consists of accident analyses, demonstrations and pilot tests, simulator studies, and emergency driver training courses. Each of these have inherent limitations as research, but represent the state of the art at the present time.

### (a) Describing Critical Conflict Situations

Accident analysis reports show that multi-vehicle conflicts occur at intersections, and on straight roads and highways between intersections, in both rural and urban areas. They involve two or more vehicles, all making moving maneuvers such as converging, intersecting, following, passing or approaching; and they are often instigated by faulty driver actions such as following too close, running a traffic control, or turning in front of oncoming vehicles. The critical conflict situation, as a result, occurs in very compressed time interval, which

makes normal driving skills either inappropriate or impossible.

Other accident studies found that human errors are involved in almost all accidents, and that these errors occurred in each of the three steps of the critical conflict response process: perception (recognition of conflict), decision (response selection), and implementation (of proper evasive action). One study showed that of all drivers in conflict situations, 46% did not perceive the danger in time to attempt evasive action.

(b) Skills Involved in the Collision Avoidance Response

The critical conflict situation, then, demands above-average perception, decision-making, psychomotor and manipulative skills, under the added stresses of speed, accuracy, task and information load. Straight braking alone is not generally the best avoidance response. Relatively simple skills of braking, steering and accelerating must be transformed into a highly co-ordinated reaction requiring additional skills of rapid acceleration, modulated braking and evasive steering. These skills are different from normal driving skills, and may even conflict with them. They require a different type of training, and must be overlearned to the point that normal driving skills are overlearned.

(c) What Drivers Do - An Overview

On general observation, drivers in critical conflict situations have difficulty in performing evasive steering and modulative braking responses properly when these have to be carried out concurrently with perception, response selection and motor

responses. Improper evasive actions are mainly failure to attempt appropriate evasive steer, or negation of what would have been a successful evasive steer through over-braking, with resulting front wheel lock-up, making steering input ineffective. It was found that 38% of accident drivers in conflict situations, who had time to attempt evasive maneuvers, steered straight only and braked with the intent to stop before the object. Many of these are likely doing this out of panic or instinct, rather than it being a consciously selected response. Whatever their evasive action, the magnitude and speed of the response (especially for novices) is generally too small or too slow to be effective. There is also a problem of loss of control during the recovery phase of the avoidance maneuver.

(d) What Drivers Do - Braking

It has been estimated that 2 million severe braking maneuvers involving passenger vehicles occur every day in the United States. Studies have shown that drivers are inefficient in modulating brakes in severe braking maneuvers in order to obtain the maximum deceleration potential available to them, especially on slippery surfaces. About 45% of drivers in conflict situations locked-up their wheels sometime during the avoidance attempt.

There is a definite difference in stopping distance with different braking techniques, and except for high speed situations on low friction surfaces, 4-wheel lock does generally produce shorter stopping distances, but untrained drivers have trouble achieving 4-wheel lock. Rear-wheel lock generally produces skidding or slewing.

Four-wheel and front-wheel lock also makes steering input impossible. It has been estimated that 10 - 15% of accidents involved locked wheels, and that 70% of these (4 - 7.5% of all accidents) could have been avoided if steering input could have been used. Anti-lock devices have been proposed, to both maximize the available deceleration on slippery surfaces, and to maintain steering capability.

(e) What Drivers Do - Steering

Studies on steering, as a skill separate from braking, note that drivers in critical conflict situations expend more effort and increase their steering control responses as task difficulty increases. Despite these efforts, avoidance attempts are not always successful when available response time is very low, and in the process, drivers may turn the wheel so abruptly that they lose control of the vehicle. Both experienced and inexperienced drivers have the same initial input to avoid an obstacle, but experienced drivers display more stable performance in subsequent control of the vehicle.

(f) Perception and Decision-Making Skills

There is some feeling in the literature that the emphasis in advanced driver training is presently in the wrong place, that is, most courses concentrate on motor skills, with little or no emphasis on perceptual and response selection skills. Some studies have given attention to perceptual skills, in relation to field dependence/ independence (the ability of the driver to extract information from the environment in order to classify a

situation as threat/no threat). Driver decision-making, or response selection, has been discussed by one author with a "game theory approach", in an attempt to explain why a driver might choose an "incorrect" strategy (such as straight braking) that may not ensure crash avoidance, but will minimize loss regardless of what the other driver does. Other authors maintain that decisions are not the rational conclusion of a reflective process, but are influenced by time, prejudice, overconfidence, fear or aggression.

## CONCLUSIONS

This literature review reveals that research in emergency maneuvers could have a high pay-off in reducing accidents. With the exception of the studies supported by NHTSA (Bathurst, 1980; Hatterick and Bathurst, 1976; and Hatterick and Pain, 1977), there has been no integrated approach to the topic of driver-induced evasive maneuvers in critical conflict situations. Despite the flurry of activity that seems to have taken place, we really do not know very much about what drivers do. This report must conclude, as have all reports reviewed, that additional research is required.

It is recommended, however, that more research not be done to demonstrate that emergency maneuvers are important in accidents. The studies, to date, have established this with a reasonable degree of confidence.

This review also shows that any comprehensive investigation of emergency maneuvers must clearly include decision making and response selection, in addition to the vehicle control skills of steering, accelerating and braking.

Finally, the literature just reviewed shows quite clearly that any future studies must be conducted using proper design, appropriate controls, adequate sample size and detailed definitions of braking, steering, and accelerating techniques.

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